Confining Strata Beneath Injection Zone

Immediately underlying the Injection Interval for WDW-164 is a shale interval that is traceable across the entire local AOR and ranges between 30 feet to over 100 feet in the AOR. The confining strata beneath the Injection Zone are comprised of shales and silts of the Vicksburg-Jackson Groups. Consistent with the porosity and permeability of the overlying Confining Zone shales, it is anticipated that the porosity and permeability of the Vicksburg-Jackson Groups are sufficient to contain any injected fluids which may migrate below the Injection Zone. The thickness of the lower confining strata beneath Ineos injection wells is estimated to have a minimum thickness of 550 feet in the AOR.

4.2.5 Local Structural Geology

Plate 4-3 is a base map showing the local structural cross section locations and well control used for mapping and cross section construction through the Ineos AOR. Plates 4-1 (Northwest-Southeast Geologic Dip Cross Section) and 4-2 (Northeast-Southwest Geologic Strike Cross Section) illustrate the continuity of the Confining Zone, Injection Zone, and Injection Interval within the AOR. The WDW-163, WDW-164 and WDW-165 well locations are identified on the strike cross section.

AOR structural contour maps for the tops of the Confining Zone, Injection Zone, upper Frio and middle Frio Formations are presented as Plates 4-4, 4-5, 4-7 and 4-9, respectively. As shown on Plate 4-9, average dip of the middle Frio Formation is to the southeast at approximately 280 feet/mile.

Johnson and Mothy (1957) state in their report that, "Calhoun County, seemingly an exception to the trend, is bisected by several up-to-the-coast faults which also form oil traps". They further give the Sheriff, Green Lake, and Long Mott fields as typical up-to-the coast fault trap fields and show up-to-the-coast antithetic gravity faulting to exist (at depth) in the Heyser Field area. Though the up-to-the-coast faulting in the Heyser Field was confirmed, the antithetic character was not established. All of the fields mentioned are in Calhoun County and, with the exception of the Heyser Field which is immediately north of the AOR, are to the southeast and/or east of the AOR. These fields are depicted on Figure 4-3 and Figure 4-15.

As shown on Plates 4-7 and 4-9, the dip of the top of the upper Frio Formation is approximately 132 feet/mile to the southeast. This dip is very consistent with regional dip. Any localized faulting principally affects the deeper zones, as discussed above. Any deeper faults, if present at the depths of the WDW-164 and WDW-165 Injection Intervals, are modeled as laterally transmissive in order to conservatively maximize updip plume movement.

Fault Transmissivity

As discussed in Section 4.1.4, there is evidence that regional fault trends do not allow any significant vertical migration of fluids above the Catahoula Tuff Formation. Evidence for vertical closure includes the presence of trapped natural gas and oil in the Catahoula Tuff Formation where structural traps exist in the three-county area. If fault trends were active conduits for vertical fluid migration to aquifers and sources of drinking water, buoyant hydrocarbons would be detected in USDW aquifers. No hydrocarbons from the Frio or Catahoula reservoirs have been detected in area USDWs.

Confining Zone Faults

Based on all mapping performed and literature researched, the Confining Zone is laterally continuous and free of transecting, transmissive faults or fractures over an area sufficient to prevent the movement of fluids into a USDW or fresh water aquifer.

Well Logs

Separate copies of selected one-inch well logs from artificial penetrations within the regional study area, evaluated during the preparation of this Petition re-issuance, are included in Appendix C. These include copies of one-inch well logs from the wells that appear on the local cross sections. Copies of the Ineos injection well open hole logs are included in Appendix D.

4.2.6 Surface Geology

The Beaumont Formation and Holocene alluvium are exposed at the surface at the Ineos facility and over the AOR. The Beaumont Formation is composed primarily of clay and silt, with some sand. The alluvium is composed of clay, silt, sand, and gravel. Elevation at the site is approximately 45 feet above sea level. Figure 4-3 (Surface Geology Map), shows sediment cover of the Beaumont Formation over all of the AOR.

4.3 Injection Intervals Reservoir Characteristics

The Injection Intervals have sufficient permeability, porosity, thickness and areal extent to prevent migration of constituents from the Injection Zone into a USDW or fresh water aquifer. A summary of the reservoir parameters, bottom-hole pressure (BHP) and bottom-hole temperature (BHT), and fracture gradient is provided in the following sections.

4.3.1 Lithology

During the drilling and completion of the Ineos injection wells, whole and sidewall cores were collected (see Appendix E). Particle size analyses of sand samples taken from cores from depths of 5,345 feet, 5,375 feet and 5,612 feet in WDW-163 were conducted (Appendix E). The sands were determined to be fine-grained, containing less than 10 percent medium sand, 66 to 75 percent fine sand, 5 to 8 percent very fine sand, and 11 to 18 percent silt or finer.

Petrographic analyses were also performed on WDW-163 full hole core samples from 5,378 to 5,379 feet and 5,612 to 5,613 feet (Sands No. 2 and No. 4; Appendix I). The petrographic analyses (see Appendix I) revealed the sands to be: "Poorly consolidated, moderately sorted, fine to medium-grained sandstones, which can be classified as arkosic arenites. Monocrystalline quartz, potassium feldspars, lithic fragments, plagioclase feldspars and polycrystalline quartz comprise the framework grains. Rarely occurring secondary quartz overgrowths, secondary feldspar overgrowths and authigenic pyrite are the cements present in these samples. A grain-coating matrix of clay and fine silt is observed in thin section analyses. Visible porosity occurs as primary inter-granular porosity, with lesser occurrences of secondary intra-granular porosity" (quoted from Summary of Petrographic Study, Appendix I).

Petrographic analyses of core samples collected from the middle and lower Frio Formation in WDW-164 were also conducted (Appendix I). The sample from 6,968 feet (within the WDW-165 Injection Interval) is light gray, moderately sorted, moderately consolidated, medium grain sandstone. The sample shows a loosely packed aggregate of subangular to subrounded sand grains cemented by pore filling, authigenic clay. The original intergranular porosity has been reduced by the presence of authigenic clay; however, substantial porosity remains. In addition, dissolution of feldspar grains, suggests a source for secondary porosity, and the crystalline structure of authigenic clay creates significant microporosity.

In addition, X-Ray diffraction analyses were conducted on WDW-164 core samples collected from the WDW-165 Injection Interval. These analyses revealed that the WDW-165 Injection Interval sand contains: 77 percent quartz, 15 percent feldspar, 2 percent calcite, and approximately 6 percent or less clay minerals in the form of kaolinite, montmorillonite, illite/mica, chlorite and mixed layer clay.

4.3.2 Porosity and Permeability

WDW-163 - Upper Frio

Full hole core samples were obtained during the drilling of WDW-163 (Appendix E). The following core runs (CR) and samples were obtained:

Depth	Recovery	Stratigraphic Interval
CR1 4,900' – 4,920'	18' 3"	Anahuac shale
CR2 5,340' – 5,360'	20'	upper Frio Sand No. 2
CR3 5,360' – 5,380'	20'	upper Frio Sand No. 2
CR4 5,600' – 5,620'	17'	upper Frio Sand No. 4

In addition to the full hole cores, 15 sidewall cores were obtained between the depths of 4,720 feet and 5,725 feet (Appendix E). Analyses for permeability (to air) and porosity of 33 plugs removed from the full hole cores (Appendix E) yielded a range in permeability between 770 and 7,200 mD for the sand intervals and a porosity range between 30 and 42.5 percent. The full hole core from CR1 (4,900 to 4,920 feet) was not tested because testing shale was not standard core laboratory practice at the time the well was installed.

Sidewall core analyses yield a porosity range from 20.4 percent in very fine grain shaley sand to 32.9 percent for silty sand. Air permeabilities ranged from 7.8 to 2,663 mD in the same core samples. These values for sidewall core analyses may be lower than those for the full hole cores due to densification of the sidewall core when collected.

A neutron-density porosity log was also run over the WDW-163 Injection Interval during drilling, and the section covering the WDW-163 Injection Interval is included in Appendix D. This log indicated a porosity value range of 30-38 percent over the sands within the Injection Interval, with an average value of approximately 34 percent.

WDW-164 and WDW-165 – Middle to Lower Frio Sands

Full-hole cores were obtained from WDW-164 as follows:

Depth	Recovered	Stratigraphic Interval
CR1 6,962' - 6,982'	20'	middle Frio Formation
CR2 7,416' - 7,426'	No Recovery	middle Frio Formation
CR3 7,539' - 7,559'	20'	lower Frio Formation
CR4 7,559' - 7,579'	6'	lower Frio Formation

In addition to the full hole cores (Appendix I), 45 sidewall cores were obtained from WDW-164 between the depths of 6,620 feet and 8,038 feet (Appendix E). No full hole cores were obtained during the drilling of WDW-165. However, 45 sidewall cores were obtained between the depths of 5,300 feet and 7,435 feet (Appendix E). WDW-164 penetrated the effective Injection Intervals for both WDW-164 and WDW-165. Consequently, the core analyses results for these samples span both intervals. The ranges in values given below are based upon all core samples, whether taken from WDW-164 or WDW-165.

The air permeability and porosity based upon full hole core analyses samples from the WDW-164 effective Injection Interval ranged, respectively, between 325 and 3,620 mD and 26.9 and 37.9 percent (Appendix I; page 3 of 33 of Well 2 Special Core Analysis Study). Corresponding values for sidewall cores ranged between 2.9 and 428 mD and porosity between 20.1 and 32.3 percent, respectively. For reasons discussed previously, sidewall core values appear lower.

Based upon full hole core sample analyses (Appendix I; page 3 of 33 of Well 2 Special Core Analysis Study) of the WDW-165 Injection Interval recovered from cores of that interval in the WDW-164 well, the air permeability ranges between 442 and 2,840 mD, and the porosity ranges between 29.7 and 36.4 percent. Sidewall core analyses from the WDW-165 Injection Interval (Appendix E) yielded values of 31 mD (very shaley sand) to 1,495 mD for air permeability, and 21.6 to 32.5 percent for porosity. Again, the sidewall core analyses yield lower values for permeability and porosity than the full-hole core analyses. Reasons for this were given previously.

4.3.3 Thickness

The currently petitioned Injection Interval depths (reservoir thickness) for the Ineos wells are as follows:

Well No.	Petitioned Injection Interval	Thickness
WDW-163	5,370 to 5,710 feet BKB	340 ft
WDW-164	7,435 to 8,005 feet BKB	570 ft
WDW-165	6,600 to 7,500 feet BKB	900 ft

Although the petitioned Injection Intervals are approximately 340 feet, 570 feet and 900 feet thick, respectively, a smaller portion of each Injection Interval is actively receiving injected fluid. For purposes of this Petition and modeling associated with determinations of reservoir pressure buildup and waste plume dimensions, a reservoir thickness of 98 feet is assumed to be representative at WDW-163, a reservoir thickness of 338 feet is assumed to be representative at WDW-164, and a reservoir thickness of 550 feet is assumed to be representative at WDW-165. These thickness values as used in the petition modeling are discussed in Section 7.3.1. Variable thicknesses are used in both the SWIFT pressure and transport models across the areas of the model grids, representative of the mapped thicknesses as presented in the geologic isopach maps.

Plates 4-8, 4-10, and 4-11 are net thickness maps of the WDW-163, WDW-165, and WDW-164 effective Injection Intervals, respectively. The isopach maps were constructed based on net sand thickness values for each Injection Interval acquired from open hole electric logs of wells within the mapped area. The modeled sand thickness value used at WDW-163 of 98 feet is less than the actual net Injection Interval sand thickness of both Sands 3 and 4 at that well, reflecting that Sand 3 is taking the majority of the well flow. Once Sands 3 and 4 merge in downdip (as shown on the dip cross section Plate 4-1), the net thickness of both sands combined is included in the Plate 4-8 isopach map, but updip from that point only the thickness values of Sand 3 are incorporated into the isopach map. This was done to provide a conservatively large light plume movement and pressure increase over the modeling period, since all injectate into WDW-163 was directed into Sand 3, which pinches out significantly farther updip than Sand 4. The WDW-163 effective Injection Interval isopach consists of Sand 3 only updip of its coalescing with Sand 4. The Plates 4-10 and 4-11 isopach maps of the WDW-165 and WDW-164 Injection Intervals are based on the net sand thicknesses found within those mapped horizons as delineated on the cross section Plates A-A' and B-B' (Plates 4-1 and 4-2). The Figure 4-7 cross-section of the three Ineos injection wells highlights (by shading) the effective Injection Interval from which the net isopach maps were constructed.

4.3.4 Representative Modeling Values

Based on the core analysis, research of available literature, and a review of an available porosity log from WDW-163 (included in Appendix D), average porosity values were selected as representative values for the porosity of the each of the Ineos Injection Intervals.

A variety of data was also reviewed to determine a representative value of the transmissibility, flow capacity, and permeability of each Injection Interval. The investigation included consideration of literature data, core data and analysis of available transient pressure well tests conducted on the WDW-163, WDW-164 and WDW-165 injection wells. Representative porosity, permeability, thickness and reference depth values for each Injection Interval are summarized here:

Well No.	Porosity	Permeability	Thickness	Reference Depth
WDW-163	34%	500-1,600 mD	98 ft	5,422 ft KB
WDW-164	30%	40-400 mD	338 ft	7,435 ft KB
WDW-165	28%	33-147 mD	550 ft	6,750 ft KB

4.3.5 Bottom-hole Temperature

The initial BHT was determined to be 158 °F at 5,464 feet KB in WDW-163, 192 °F at 7,614 feet KB in WDW-164, and 182 °F at 6,960 feet KB in WDW-165. Due to the fact that the injected wastewater is maintained at a temperature of approximately 120 °F, current bottom-hole temperatures are slightly less than the initial BHTs measured in each well.

4.3.6 Injection Reservoir Fluid

A sample of Frio Formation brine was collected at the time of completion of the WDW-163 injection well from a depth of approximately 5,650 feet. The analysis of Frio Formation Injection Interval brine is included on Table 4-2, extracted from a Core Laboratories compatibility testing report (Appendix I). The Frio Formation brine is basically sodium chloride brine, with an estimated total dissolved solids (TDS) value of 86,700 mg/L at surface temperature and pressure. Although the constituents listed in Table 4-2 calculate out to a TDS value of 81,912 mg/L, the higher value is used in the modeling to maximize light plume movement over 10,000 years. There is some uncertainty as to whether the Core Laboratories report brine composition tabulation included all dissolved ions, or just those used to make up their synthetic brine. Due to a lack of an original laboratory analytical results sheet, the higher Intera-referenced TDS value (Appendix I) extracted from the 1994 Petition is used in the current Petition modeling. This 86,700 mg/L value is equivalent to an 8.2 percent sodium chloride brine solution (see Section 7.3.7). The density of the injection reservoir brine sample is 1.057 g/cm^3 at a surface temperature of 20 °C and 14.7 psi (STP). This was determined from Table 71 of the CRC Handbook of Chemistry and Physics (1979) (see Appendix K).

At a temperature of 158 °F (initial BHT in WDW-163), the calculated density of the injection reservoir brine is 64.9 lb/ft^3 at reservoir depth and temperature (see Section 7.3.7 for calculations). At a temperature of 192 °F (initial BHT in WDW-164), the calculated density of the injection reservoir brine is 64.3 lb/ft^3 at reservoir depth and temperature. At a temperature of 182 °F (initial BHT in WDW-165), the calculated density of the injection reservoir brine is 64.5 lb/ft^3 at reservoir depth and temperature.

The viscosity of the reservoir brine at various temperatures was calculated empirically since no specific measurement of viscosity was reported for the representative formation brine sample. Utilizing published viscosity versus temperature data from Earlougher (1977), the following viscosities were derived for the given temperatures:

Temperature (°F)	Viscosity (μ)
80	0.99
120	0.66
158	0.47
160	0.47
182	0.42
192	0.40
200	0.38

The reservoir brine viscosity is approximately 0.47 cP at a temperature of 158 °F, approximately 0.42 cP at a temperature of 182 °F, and approximately 0.40 cP at a temperature of 192 °F.

4.3.7 Static Reservoir Pressures

An initial static bottom-hole pressure (BHP) of 2,270 psi at 5,640 feet KB was measured in the WDW-163 at the time of completion of the well. An initial BHP of 3,225 psi at 7,726 feet KB was measured in the WDW-164 injection well at the time of completion. No initial BHP was measured in the WDW-165 injection well at the time of completion.

The most current static BHPs were measured in WDW-163, WDW-164 and WDW-165 in April 2006 as part of the annual ambient pressure monitoring activities. The static BHP in WDW-163 was 2,155 psia at 5,400 feet KB. The static BHP in WDW-164 was 3,019 psia at 7,475 feet KB. The static BHP in WDW-165 was 2,736 psia at 6,770 feet KB.

4.3.8 *Fracture Gradients*

The fracture gradients of the WDW-163, WDW-164, and WDW-165 Injection Intervals can be calculated using the equation developed by Hubbert and Willis (1957) and refined by Eaton (1969; Appendix K). The equation is listed below.

$$FractureGradient = \left(P_{ob} - P_r\right)\left[\frac{V}{(1-V)}\right] + P_r$$

Where:

P_{ob} = overburden pressure gradient (psi/ft)
P_r = reservoir pressure gradient (psi/ft)
V = Poisson's ratio

For the Ineos Injection Intervals the variable values are:

P_{ob} = 0.92 psi/ft (Eaton, 1969) for Gulf Coast strata
P_r (WDW-163) = 0.402 psi/ft (2,270 psi/5,640 ft)
P_r (WDW-164) = 0.417 psi/ft (3,225 psi/7,726 ft)
P_r (WDW-165) = 0.417 psi/ft (3,225 psi/7,726 ft) (equal to WDW-164)
V = 0.42 (Eaton 1969)

The calculated reservoir fracture gradients for the three Injection Intervals are:

0.78 psi/ft (WDW-163 Injection Interval)
0.78 psi/ft (WDW-164 Injection Interval)
0.78 psi/ft (WDW-165 Injection Interval)

4.4 *Nearby Hydrocarbon Production*

The producing horizons of the Heyser South and Guajolote Suerte Field wells (only production within the Ineos 2-mile radius AOR), plus those of the Heyser Field (within the 10,000-year WDW-163 plume outline) are discussed below. Additional discussion of nearby oil and gas production as it relates to the modeling is included in Section 7.3.22. The Plate 4-12 cross section (discussed below) illustrates the lack of a correlation between these fields' producing horizons and the Ineos Injection Interval sands. Due to a lack of any evidence of communication between the Ineos Injection Intervals and the producing horizons within the AOR and adjacent Heyser Field (either through stratigraphic correlations or reservoir pressure declines), no effect on the modeled plume movement and pressure buildup was incorporated into the modeling demonstration presented in Section 7.0.

Plate 4-12 is a detailed cross section through the Heyser Field, through AP No. 27, through the Ineos injection wells, and then southwest to the recently developed Guajolote Suerte Field. On this cross section, Map ID No. 19 produced oil from thin discontinuous sand stringers below Sand 3 of the WDW-163 Injection Interval. Map ID No. 70 (discussed in more detail in the next paragraph) produced from a thin sand stringer between Sands 3 and 4, and was later converted to a salt water injection well in that interval. Map ID No. 27 formerly injected saltwater into Sand 2 above the WDW-163 Injection Interval. Well No. 25B (beyond 10,000-year plume) produced from strata at the top of the Oakville Formation, substantially above the top of the Injection Zone. Map ID No. JJ (also beyond 10,000-year plume) produces from strata below Sand 3. The great majority of all production from the Heyser Field is from the 5750-foot Sand, below Sands 3 and 4 of the WDW-163 Injection Interval, and above the WDW-165 Injection Interval. The minimal production from the Heyser South Field was from the 5400-foot Sand, also located between the two Ineos Injection Intervals. Map ID No. 95 produces from thin sand stringers below Sand 4 of the WDW-163 Injection Interval. Production from this recently discovered Guajolote Suerte Field is from the 5750-foot Sand.

AP 70 does not have perforations within Sands 3 and 4 of WDW-163's Injection Interval, but is perforated into a 4-foot thick sand stringer present between these two larger sands. An expanded cross section specifically focusing on the WDW-163 Injection Interval, and connecting AP 70, AP 63, and WDW-163 is included as Figure 4-19. This cross section indicates that the sand stringer present in AP 70 is pinched out and absent in the next well (AP 63) downdip, before the more massive Sands 3 and 4 of the WDW-163 Injection Interval develop at WDW-163. The barrier bar and strandplain depositional system in which these upper Frio sands were deposited result in sand body geometries that more likely to be contiguous in a strike direction, and not in the dip direction between AP 70, AP 63, and WDW-163.

The Heyser, Heyser South, and Guajolote Suerte Fields produce from discontinuous fluvial sand strata, whereas the massive beach sand strata of the Ineos Injection Intervals are non-productive in these fields. The Plate 4-12 cross section illustrates that to the north in the Heyser and Heyser South fields, the productive horizons are primarily in thin sands between the WDW-163 and WDW-165 Injection Intervals. To the west in the Guajolote Suerte Field, production is also below the WDW-163 Injection Interval and above the WDW-165 Injection Interval.

Appendix N contains a copy of the Ineos (formerly BP Chemicals, 1994) Petition Re-issuance application discussion of the potential effects of offset hydrocarbon production. In that document, it was assumed that the Ineos Injection Intervals were initially under-pressured by some 255 psi due to the effects of historic offset hydrocarbon production, and that the native hydrostatic equilibrium resulted in hydrologic head levels for the Frio strata being initially at or near the ground surface. Figure 4-17 of the current application illustrates that the Frio strata in the regional area surrounding the Ineos facility have native hydrologic heads substantially below ground surface. Appendix F of the Petition re-issuance document contains the completion reports for the Ineos wells. WDW-163 is recorded as having an initial measured fluid levels substantially below surface (890 feet), and WDW-164 had an initial bottom-hole pressure (see Section 7.3.12) also indicating a native hydrologic head hundreds of feet below ground surface. The regional hydrologic head map (Figure 4-17) indicates similar subsurface head levels for the Frio strata at the depths of the Ineos Injection Intervals at the facility.

The assumptions initially provided with the Ineos (formerly BP Chemicals, 1988) Petition application (Section 10.3.3 of that document; included in Appendix N) inaccurately assumed a native brine specific gravity of 1.06 for the Ineos Injection Intervals, substantially higher than that determined from the WDW-163 brine (1.03-1.04; see Section 7.3.7). Thus the 1988 assumptions regarding under-pressuring of all three intervals calculated a 255 psi subnormal pressure for each interval based on this higher specific gravity value in comparison with an unsubstantiated normal "hydrostatic equilibrium" value for each Injection Interval. This reasoning over-estimated the native hydrostatic pressure at the actual depths that initial pressures were measured in the Ineos wells, as it assumed a native brine fluid column at or near to the surface, which from actual well measurements and regional studies of the Gulf Coast (see Figure 4-17) is shown to be incorrect. There does not appear to be any initial under-pressuring present within the Ineos Injection Intervals due to nearby hydrocarbon production, and such effects have not been incorporated into the modeling. The massive beach sands of the three Injection Intervals appear to be normally pressured within the Frio Formation strata of this area. It is only the thin fluvial sands in the surrounding fields which are productive, and these do not appear to be in communication with the Ineos Injection Intervals.

References

Algermisson, S.T., 1969, "Seismic Risk Studies in the United States", *in* Proceedings of the Fourth World Conference on Earthquake Engineering: Chilean Association for Seismology and Earthquake Engineering, Santiago, Chile, pp. 20.

Aronow, S. and V.E. Barnes, 1982, Geologic Atlas of Texas, Houston Sheet: The University of Texas at Austin, Bureau of Economic Geology, Scale 1:250,000, Revised Edition.

Baker, E.T., Jr., 1979, Stratigraphic and Hydrogeologic Framework of Part of the Coastal Plain of Texas: Texas Department of Water Resources, Report 236, 43 p.

Bebout, D.G., O.K. Agagu, and M.H. Dorfman, 1975, Geothermal Resources Frio Formation, Middle Texas Gulf Coast: The University of Texas at Austin, Bureau of Economic Geology, Geologic Circular No. 75-8, 43 p.

BEG, 1992, Geology of Texas Map: The University of Texas at Austin, Bureau of Economic Geology, Scale 1" = 100 miles, 1 p.

BP Chemicals, Inc., 1988, Deepwell No-Migration Petition Exemption for Green Lake Complex, Port Lavaca, Texas: KEDA, 3 volumes.

BP Chemicals, Inc., 1994, Reissuance of Deepwell No-Migration Petition Exemption for Green Lake Complex, Port Lavaca, Texas: Intera, 4 volumes.

Brown, L.F., Jr., R.A. Morton, J.H. McGowen, C.W. Kreitler, and W.L. Fisher, 1974, Natural Hazards of the Texas Coastal Zone: The University of Texas at Austin, Bureau of Economic Geology, Special Report.

CRC Handbook of Chemistry and Physics, 1979, Lide, D. R., editor, CRC Press, Boston, 58th Edition.

Dodge, M.M., and J.S. Posey, 1981, Structural Cross Sections, Tertiary Formations, Texas Gulf Coast: The University of Texas at Austin, Bureau of Economic Geology, 6 p, 2 figs., 32 plates.

Earlougher, R.C., 1977, "Advances in Well Test Analysis", H.L. Doherty Series, Monograph Vol. 5, Society of Petroleum Engineers of AIME, 264 p.

Eaton, B.A., 1969, "Fracture Gradient Prediction and its Application in Oilfield Operations": Journal of Petroleum Technology, pp. 1353-1360.

Gabrysch, R.K., 1980, Development of Ground Water in the Houston District, Texas, 1970-1974: Texas Department Water Resources, Report 241, 49 p.

Galloway, W.E., T.E. Ewing, C.M. Garrett, N. Tyler, and D.G. Bebout, 1983, Atlas of Major Texas Oil Reservoirs: The University of Texas at Austin, Bureau of Economic Geology, pp. 3-23.

Galloway, W.E., D.K. Hobday, and K. Magara, 1982, Frio Formation of the Texas Gulf Coast Basin - Depositional Systems, Structural Framework, and Hydrocarbon Origin, Migration, Distribution, and Exploration Potential: The University of Texas at Austin, Bureau of Economic Geology, Report of Investigations No. 122, 78 p.

Geomap, 1996, Structure Map TGC-11, Contoured on Horizon A - Top Frio and Horizon B - Top Textularia Warreni: Geomap Company, Houston, Texas, Map Scales 1" = 4,000'.

Holcomb, C.W., 1964, Frio Formation of Southern Texas: Gulf Coast Assoc. of Geol. Socs. Trans. V. 14.

Hubbert, M.K., and D.G. Willis, 1957, "Mechanics of Hydraulic Fracturing": Transactions of Society of Petroleum Engineers of AIME, v. 210, pp. 153- 168.

Johnson, R.B. and H.E. Mothy, 1957, The South Texas Frio Trend: Gulf Coast Assoc. Geol. Socs. Trans. V. 7.

Ken E. Davis Associates, 1987, TWC Permit Renewal Application for WDW-163, WDW-164, and WDW-165.

Kreitler, C.W., 1979, Ground-Water Hydrology of Depositional Systems, *in* Galloway, W.E., et al., Depositional and Ground-Water Flow Systems in the Exploration for Uranium, a research colloquium: The University of Texas at Austin, Bureau of Economic Geology, pp. 118-176.

Kreitler, C.W., and S. Akhter, 1987, Hydrologic Characterization of the Saline Frio Formation, Victoria County, Texas Gulf Coast: A Case Study: The University of Texas at Austin, Bureau of Economic Geology, Interim Report prepared for the U.S. EPA under cooperative agreement no. CR812786-01-0, 36 p.

Kreitler, C.W., and B. Richter, 1986, Hydrochemical Characterization of Saline Aquifers of the Texas Gulf Coast Used for Disposal of Industrial Waste: The University of Texas at Austin, Bureau of Economic Geology, Annual Report prepared for the U. S. EPA under contract no. R-812785-01-0, 164 p.

McGowen, J.H., C.V. Proctor, Jr., L.F. Brown, Jr., T.J. Evans, W.L. Fisher, and C.G. Groat, 1976, Environmental Geologic Atlas of the Texas Coastal Zone – Port Lavaca Area: The University of Texas at Austin, Bureau of Economic Geology, 107 p.

National Oceanic and Atmospheric Administration (NOAA), 2001, Earthquake Database Search Within 30 KM of 28N34'00", 96W50'14", National Geophysical Data Center, Boulder, Colorado: Letter to Terra Dynamics Incorporated, Austin, Texas.

Ryder, P.D., 1988, "Balcones Fault System: Its Northeast Extent": American Association of Petroleum Geologists Bulletin, Vol. 45, pp. 1759-1762.

Turcan, A.N., Jr., 1966, Calculation of Water Quality from Electrical Logs - Theory and Practice: Louisiana Geological Survey, Water Resources Pamphlet 19, 23 p.

United States Geologic survey, 1982, State of Texas (SE) 1:500,000 Scale Base Map.

United States Geologic Survey, 1995, Green lake 7.5 Minute Topographic quadrangle map.

United States Geologic Survey, 2008, NEIC Earthquake Search Results in a 30-km Radius centered at Latitude 28.567N and Longitude 96.837W.

Wesselman, J.B., 1972, Ground-Water Resources of Fort Bend County, Texas: Texas Water Development Board, Austin, Texas, Report 155, 176 p.

Williamson, J.D.M., 1959, Petroleum Geology of the Cenozoic of the Central Gulf Coast, with Special Emphasis on the Miocene: Gulf Coast Assoc. of Geol. Socs., Readings in Gulf Coast Geology v. 2, 1981.

Wood, L.A., R.K. Gabrysch, and R. Marvin, 1963, Reconnaissance Investigation of the Ground-Water Resources of the Gulf Coast Region, Texas: Texas Water Commission, Bulletin 6305, 26 p.

TABLE 4-2

FRIO FORMATION BRINE SAMPLE FROM WDW-163

Core Laboratories

WDW-163
Port Lavaca, Texas

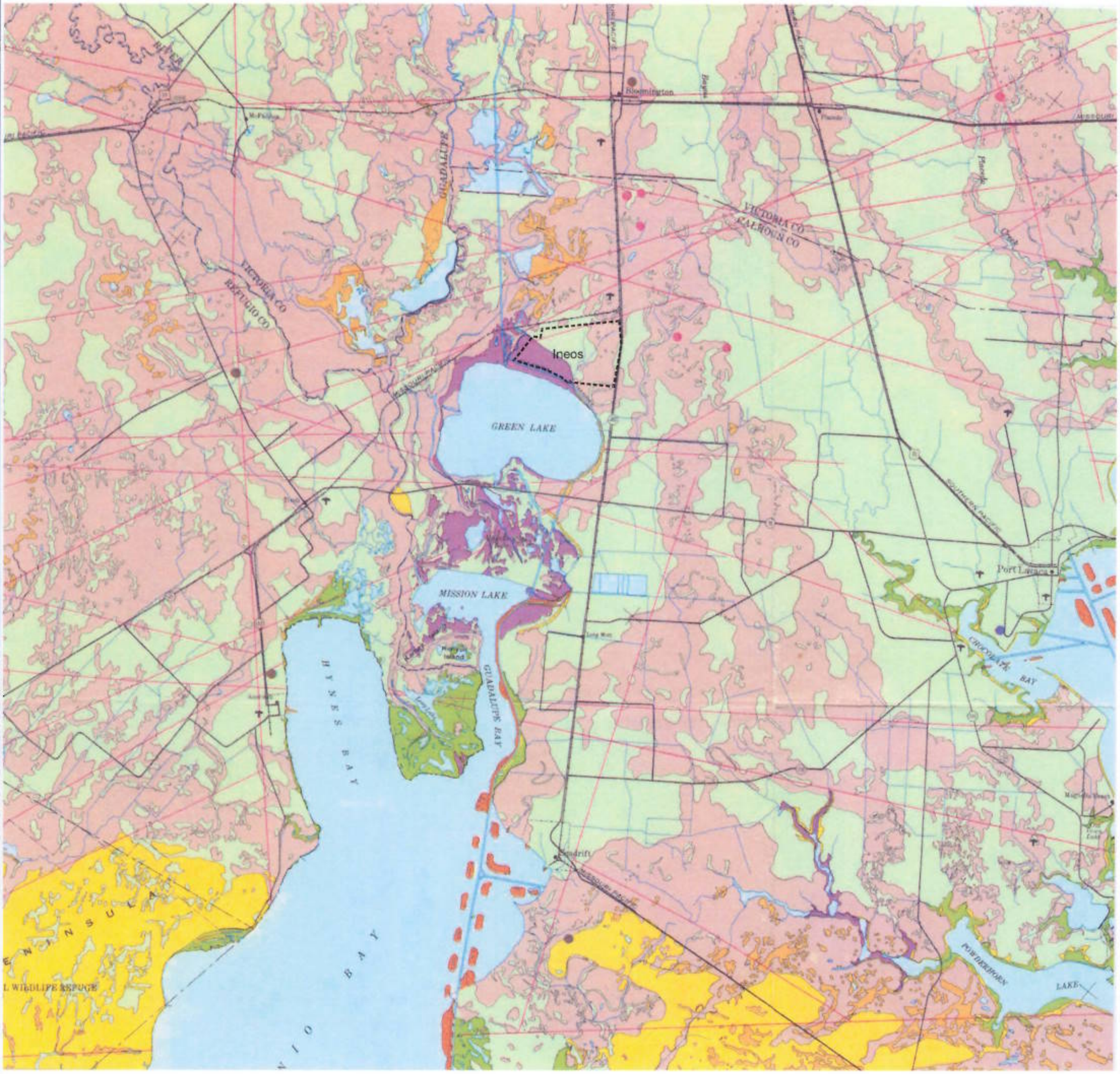
Component	Concentration mg/liter
Barium	16
Bicarbonate	177
Calcium	2,160
Chloride	50,700
Magnesium	220
Potassium	150
Sodium	28,130
Strontium	272
Sulfate	87

Source: 1984 Core Laboratories Report
Fluid collected from WDW-163 during completion in December 1983

MAY - 6 2009

Drawing No.: Figure 4-14.cdr
Date: 4-13-09
Job No.: 08-160

Drawn By: Fisher and others, 1974
Designed By: same
Checked By: TDM



LEGEND

- Pit or quarry, commonly shelly beach and delta front sands
- Sludge pit or miscellaneous waste disposal site, may be abandoned
- Sewage disposal site, liquid effluent, normally treated
- Solid-waste disposal site, sanitary landfill, and open dumps
- Active or potentially active fault, based on lineament or grain displayed on aerial photographs

Scale 1:250,000

0 5

Miles

MAY - 6 2009

N

FIGURE 4-14

LINEAMENT MAP OF PROJECT AREA

PREPARED FOR

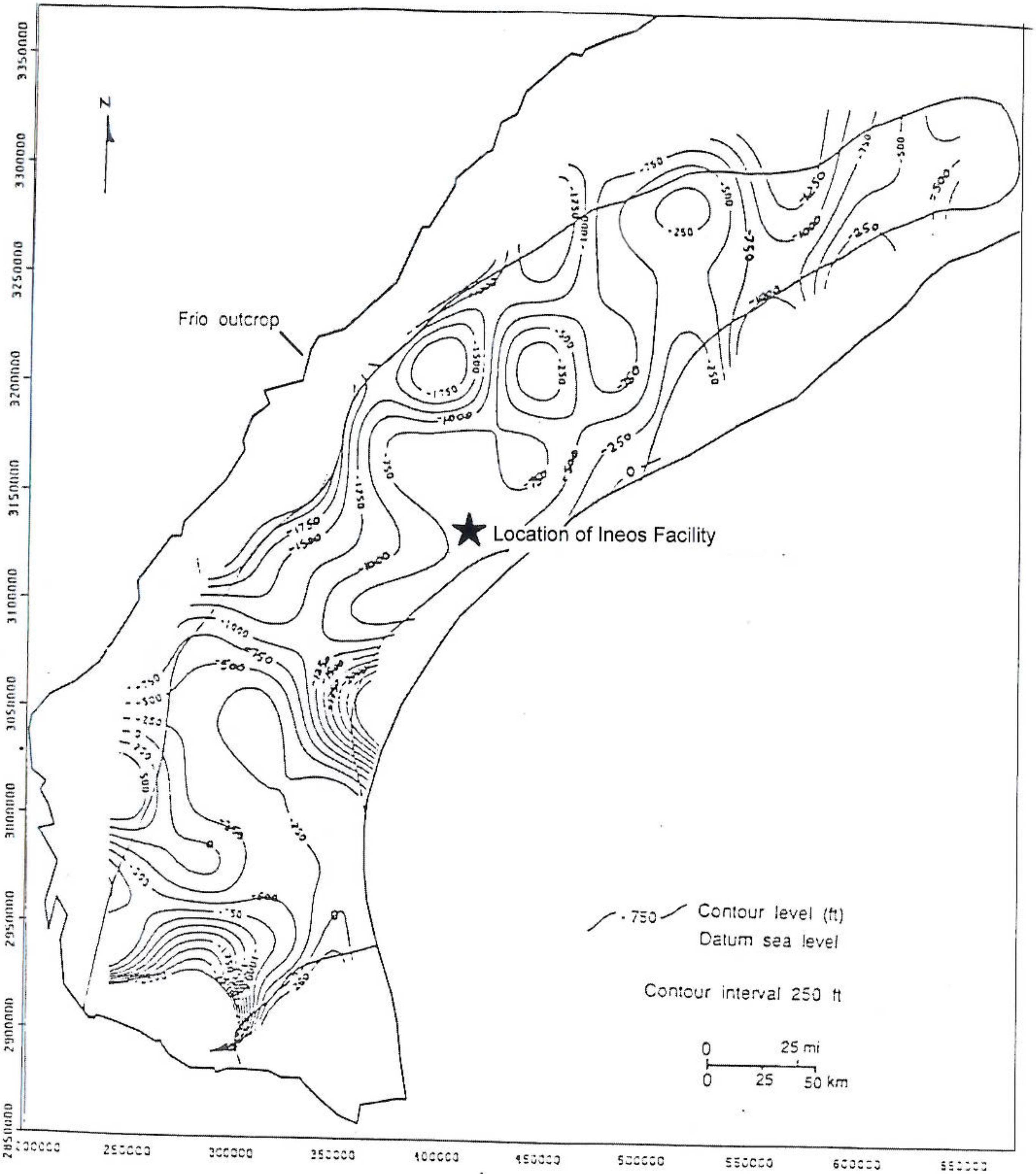
INEOS USA LLC
PORT LAVACA, TEXAS

TERRA DYNAMICS INC

Source: McGowen and others, 1976

Drawing No.: Figure 4-17.cdr
Date: 4-13-09
Job No.: 08-160

Drawn By: Krietler, and Akhter, 1987
Designed By: same
Checked By: same



Source: Krietler and Akhter, 1987

FIGURE 4-17

HYDROLOGIC HEAD MAP
FRIO FROMATION SANDS AT
4,000' - 6,000'

PREPARED FOR

INEOS USA LLC
PORT LAVACA, TEXAS

TERRA DYNAMICS INC